INTERCONNECTED SURFACE DESIGN APPROACHES BY STRUCTURAL ANALYSIS OPTIMIZATION

Strategies to optimize interconnected structures by analysis data. Design, analysis, synthesis, evaluation.

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Abstract

This is a method for designing interconnected surface structures, a common and complex component of architecture, using an optimized analysis. Structures are omnipresent in the industrialized world and architecture appearing as roof supports, slabs or building exoskeletons, yet are complex enough that modeling them by conventional software is time-consuming and tedious. This method represents structures as a set of rigid bars connected by pin joints and supported by minimum amount of columns, which may change location during optimization. By including the location of the joints as well as the strength (stress, displacement, deformation) of individual beams in the design variables, the method can simultaneously optimize the geometry.

CR Categories: [Computer Graphics]: 3d-NURBS-Modeler (Rhinoceros™-Grasshopper) and Object Modeling—Physically based modeling;
[Numerical Analysis]: SolidWorks
Keywords: Performance Design, constrained optimization, nonlinear optimization

Method

Surface-based design have become used in architecture through B-Spline-modeling software. A surface can serve as a representation for many different aspects of a design beyond its initial function. It is a two-dimensional object unfolded into the three-dimensional space. However, instead of being surfaces as border conditions, they are often perceived as the objects themselves. This represents a physical building component that is developed when the surface is translated into a building with structural requirements and material properties. The strategy of the structural analysis optimization introduced into the design permits a minimum number of constraints, minimum stress and deformation-displacement.
The method used in this research generates a mesh of structural elements along the initial surface. As shown in Figure 1 the developed design process starts with a flexible grid on a surface. The different iterations are summarized in three. Figure 2. One initial surface is translated into SolidWorks software, which then is exposed to gravity with perimetric constraints. Figure 3-4. The resulting mesh deflection with appropriate reactions towards the local stresses and deformations is fed back into Rhino-Grasshopper and translated to SolidWorks to its dead load using minimum amount of constraints. Figure 5

The geometry of the initial mesh is altered to reduce bending. This process negotiates the form-driving ‘forces’, the structural and the architectural. The new, altered mesh then is transformed back into either a single surface in the 3d-modeling software. In the latter case the in-between space now describes a volume for space frame construction. Figure 6
From this new starting point a Grasshopper definition is used to find a solution of a space frame which deals with closest points. In Figure 7-8-9 these factors are represented by spaces which should be free of structural elements, a minimal number of structural members, and a minimum of overall deviation. The structural analysis data, which result from that next feedback loops, Figure 10 finally are used to generate in a simplified, but parametrically driven manner, all structural members of the developed space frame system. The project uses a 3d-NURBS-Modeler (Rhinoceros™) for surface generation, surface modification and the visualization of geometry. Structural analysis is done in SolidWorks.
Conclusions

Integrating form-finding into a design process with parameters proved successful. Altering the geometry while maintaining the architectural expression led to less deformation in the shape. At the same time the formal collection is not limited to shapes that are force-driven. Being able to transfer the data from a surface model to a structural mesh and back again provides a fast and easy way to improve the model. The design process is driven by architectural and structural parameters simultaneously. The negotiation between different aspects gives solutions which are improved during the generative process. The procedure is seen as an approximation for the early design stage that offers architects the possibility to integrate structural aspects into their work and use them as design tool. The use of Rhino-Grasshopper definitions within the design process is a powerful method to generate variation and at the same time search a solution space. Especially when searching for a balance of multiple or even conflicting interests this approach is beneficial.
References


MICHELL, A. 1904. The limits of economy of material in frame structures. Philosophical Magazine 8, 589-597.


Software

Rhinoceros Nurbs Modeling
Grasshopper Generative Modeling for Rhino
SolidWorks
AutoDesk Maya 2009